NASA-CR-204305

Aeroelastic Stability Response of Rotating Strucutres Annual Report

NASA Grant No. NCC3-446
Duration: January 8 1996 to January 7, 1997

During the current research period, an updated users manual was written for the ASTROP2 code. ASTROP2 is an aeroelastic code based on the two-dimensional linear unsteady aerodynamic equations, and the three-dimensional structural dynamic equations. The original program was modified, and extended, which also required the writing of a new users manual. The manual was published as NASA TM 107195, Ref. 1.

The multistage code developed in Ref. 2 was modified and applied to predict the gust response for the turbine airfoils tested in Ref. 3. The results were reported in Ref. 4. A users manual was also written for this multistage code, Ref. 5. The manual has a number of example problems with sample input and output. The code and the manual were delivered to researchers at Wright Patterson Air Force Base, and can be used in support of their experimental work. During this period, the algorithm in the multistage code was updated. This algorithm is more robust and computationally efficient than the one used earlier. Viscous terms were added to allow the code to be used for flutter prediction in separated flows.

Also, in this period, a ducted fan code based on the three-dimensional nonlinear Euler equations was developed and validated by comparing with published results. Time domain and frequency domain solutions were obtained. The findings were reported in Refs. 6 and 7. Also, a users manual was written for the propeller code based on the three-dimensional Euler equations and a three- dimensional structural model, Ref. 8.

References:

1. Reddy, T.S.R. and Lucero, J.M., ASTROP2 Users Manual: A Program for Aeroelastic Stability Analysis of Propfans, Version 2.0, NASA TM 107195, March 1996.

2. Reddy, T.S.R. and Srivastava, R., Analysis of a Rotor-Stator Stage using a Two Dimensional Euler Aeroelastic Solver, AIAA-94-1638, 35th SDM Conference, April 18-20, 1994, Hilton Head, SC.

3. Kurkov, A.P. and Lucci, B.L., Measurement of Gust Response on a Turbine Cascade, ASME-95-GT-96, International Gas Turbine and Aeroengine Congress and Exposition, Houston, Texas, June 5-8, 1995.

4. Reddy, T.S.R., Gust and Structural Response Analysis of a 2D Cascade Using an Euler Aeroelastic Solver, AIAA-96-1492, 37th AIAA/ASME/ASCE/ASC

Structures, Structural Dynamics, and Materials Conference and Exhibit, April 15-17, 1996, Salt Lake City, UT.

5. Reddy, T.S.R. and Srivastava, R., User's Guide for MSAP2D: A Program for Unsteady Aerodynamic and Aeroelastic (Flutter and Forced Response) Analysis of Multistage Compressors and Turbines, Version 1.0, in print.

6. Srivastava, R. and Reddy, T.S.R., Aeroelastic Analysis of Ducted Rotors, to be presented at ASME 1995 IMECHE meeting, 12-17 November, San Francisco, CA

7. Srivastava, R., Reddy, T.S.R. and Stefko, G.L., A Numerical Aeroelastic Stability Analysis of a Ducted-Fan Configuration, AIAA-96-2671, 32nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference, July 1-3, 1996, Lake Buena Vista, FL

8. Srivastava, R. and Reddy, T.S.R., PROP3D: A Program for 3D Euler Unsteady Aerodynamic and Aeroelastic (Flutter and Forced Response) Analysis of Propellers, version 1.0, April 1996, NASA CR 198471.

Reports prepared from Oct.ober 95to September 96

1. Srivastava, R. and Reddy, T.S.R., Aeroelastic Analysis of Ducted Rotors, ASME 1995 IMECHE meeting, 12-17 November, San Francisco, CA

2. Reddy, T.S.R. and Lucero, J.M., ASTROP2 Users Manual: A Program for Aeroelastic Stability Analysis of Propfans, Version 2.0, NASA TM 107195, March 1996.

3. Srivastava, R. and Reddy, T.S.R., PROP3D: A Program for 3D Euler Unsteady Aerodynamic and Aeroelastic (Flutter and Forced Response) Analysis of Propellers, Version 1.0, April 1996, NASA CR 198471.

4. Reddy, T.S.R. and Srivastava, R., Gust and Structural Response Analysis of a 2D Cascade Using an Euler Aeroelastic Solver, AIAA-96-1492, 37th AIAA/ASME/ASCE/ASC Structures, Structural Dynamics, and Materials Conference and Exhibit, April 15-17, 1996, Salt Lake City, UT.

5. Srivastava, R., Reddy, T.S.R. and Stefko, G.L., A Numerical Aeroelastic Stability Analysis of a Ducted-Fan Configuration, AIAA-96-2671, 32nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference, July 1-3, 1996, Lake Buena Vista, FL

6. Reddy, T.S.R. and Srivastava, R., User's Guide for MSAP2D: A Program for Unsteady Aerodynamic and Aeroelastic (Flutter and Forced Response) Analysis of Multistage Compressors and Turbines, Version 1.0, in print.

CAST

Continuation Research Proposal
Submitted to

NASA Lewis Research Center
Cleveland, Ohio

by

The University of Toledo
2801 West Bancroft Ave.
Toledo, Ohio 43606

AEROELASTIC STABILITY AND RESPONSE OF ROTATING STRUCTURES

Project Coordinator: Theo G. Keith, Jr.
Mechanical Engineering

Social Security Number: [redacted]

New or Renewal Request: renew

Starting Date: February 1, 1997

Proposed Duration: nine months

Amount Requested: $70,000

Endorsements

Project Coordinator

Name: Dr. Theo G. Keith, Jr.

Signature: Theo G. Keith Jr.

Title: Distinguished University Professor

Telephone: (419) 530-8232

Date: December 9, 1996

Institutional Administration

Name: Dr. James Fry

Signature: James L. Fry

Title: Vice President for Research

Telephone: (419) 530-2844

Date: December 9, 1996

AEROELASTIC STABILITY AND RESPONSE OF ROTATING STRUCTURES

PURPOSE

It is proposed herein that funding be continued in support of ongoing research work to develop advanced aeroelastic stability and response computational codes for rotating structures. This year work will focus on two areas of research (1) development of FREPS-E, a fast running Forced Response Prediction System based on Euler equations, and (2) validation of the MSAP2D code with experimental data. The proposed research will be performed by Dr. T.S.R. Reddy, a Senior Research Associate.

INTRODUCTION

Current research and development within the aircraft industry is directed towards aircraft engines with considerably greater thrust. The new engine designs have resulted in new blade shapes that are radically different from conventional blade geometries. New engines such as the GE90, the Rolls Royce Trent and the P&W 4084 have ducted fans with diameters of more than 10 feet. This makes the blades flexible and prone to aeroelastic instabilities. Fatigue failures due to forced response excitations, and catastrophic failures due to flutter are two aeroelastic problems that must be avoided in the development of new engines. Recent surveys show that approximately 14 percent of development problems are related to aeroelasticity. On average, each development engine experiences four vibration problems over its lifetime.

Aeroelastic analysis requires the coupling of a structural model and a fluid dynamic model. The structural modelling is quite well developed, whereas improved fluid dynamic modelling is currently being pursued. The complex flow field associated with advanced turbomachines requires an analysis based on computational fluid dynamics models. The hierarchy of nonlinear gas dynamic equations ranges from the full potential equation to the Navier-Stokes equations, with increasing computational cost. The use of Euler equations over use of the potential equation is needed when strong shocks are expected. The use of Navier-Stokes equations is needed when viscosity effects are dominant or flow separation is expected.

The NASA Lewis Research Center has spent more than a decade in developing aeroelastic methods for fans, compressors and turbines. A review of this research is given in Ref. 1. This review indicats that aeroelastic analysis methods based on the nonlinear equations of fluid dynamics are being currently being developed. One example is the development of the

MSAP2D code, Ref. 2, a multistage aeroelastic code based on nonlinear Euler equations.

Use of nonlinear equations for aeroelastic analysis is computationally very expensive and can not be used in a design cycle. The use of linearized forms of the governing aerodynamic equations can lead to computational savings. In the linearized models, the unsteady phenomena is modeled as a linear perturbation about a steady flow. Such an approach has been used in developing FREPS, Ref. 3. FREPS can be used for both flutter, and forced response prediction of turbomachinery blades. It uses strip theory to combine a 2D aerodynamic model based on the potential equation with a 3D structural model.

PROPOSAL

Task 1: Development of FREPS-E, a fast Forced Response and Flutter Prediction System based on Two dimensional Euler Equations

Even though FREPS was successful in predicting flutter for subsonic flows, its use in transonic flow, and for flows with strong shocks, has problems. It is proposed here to use the FREPS framework, and develop a system based on the 2D Euler equations. This seems possible, since steady flow solvers using Euler equations, and linearized Euler equations are now available, Refs. 4 and 5. It is to be noted that the Euler solutions are expected to take slightly more computational time than the potential solution. Yet the computational time will be affordable in a design environment. In addition, this approach is advantagous from the standpoint that an Euler solver can be used for analyzing rotational flows, for flows with strong shocks, and can be readily extended to include viscous effects. Moreover, the Euler steady solver used here was been applied to subsonic flows, to a supersonic flow with a subsonic axial velocity, and to supersonic through flow analyses. In fact it has been tested by more researchers than the SFLOW used in FREPS..

It is proposed here to keep the basic flow chart of the FREPS the same, but carefully replace the aerodynamic modules. This requires knowledge of what input was required by FREPS from the steady nonlinear potential code SFLOW and the unsteady linearized potential code LINFLO. The new aerodynamic modules will then be linked in appropriate manner to FREPS. The relevant codes to be included are the steady nonlinear Euler code, NPHASE of Ref. 4, and the unsteady linearized Euler code, LINFLUX2D, of Ref. 5. This will result in an enhanced FREPS code based on Euler equations, appropriately termed FREPS-E. It should be noted here that the NPHASE code was validated to all flow regimes, subsonic, transonic and supersonic, and used by many researchers. The LINFLUX2D was validated in Ref. 5.

One objective of this work will be to assure that the present users of FREPS will not have to spend a great deal of time in learning FREPS-E. Therefore, the data input structure should be kept the same, to the extent possible.

SUMMARY

It is proposed to work on some or all of the following items:

Ia. Familiarize and validate NPAHSE

Ib. Familiarize and validate LINFLUX-2D

IIa. Become familiar with FREPS

IIb. Understand the input required for SFLOW, and the output required from SFLOW to LINFLOW and to FREPS.

IIb. Understand the input required for LINFLO, and the output required from LINFLOW to FREPS.

IIc. Modify NPHASE input and output to look like input and output required for SFLOW.

IIb. Modify the LINFLUX-2D input and output to look like input and output required for LINFLO,.

III Combine the segments of NPHASE, LINFLUX-2D and FREPS to form FREPS-E

IV. Validate using experimental data.

Task 2: Validation of the MultiStage Aeroelastic Code, MSAP2D, for Gust Response and Separated Flow Prediction

The review in Ref. 1 indicated the aeroelastic codes based on computational models lack validation against experimental data. To augment this deficiency, experimental data was obtained for gust response and cascade of airfoils in separated flow, Refs. 6 and 7. It is proposed here to validate the MSAP2D code by using this experimental data.

An initial attempt to validate MSAP2D for gust response prediction was made in Ref. 8. It was noted that one of the areas needing improvement is the far field boundary conditions, as suggested in Ref. 5. This involves Fourier analyzing the far field conditions at every time step and using analytical far field equations to update the unsteady flow quantities at the inlet and exit.

It is also proposed here to validate the viscous capability of the multistage code of Ref. 2. Viscous terms were recently added to the code, Ref. 4. First the viscous code will be validated for airfoils with attached flow. Then the accuracy of the the multistage solver for separated flow by comparing with experimental data of Ref. 7. Finally, couple the Navier-Stokes solver will be coupled to a typical section structural model, and the stall flutter response of cascades will be calculated.

SUMMARY

It is proposed to work on some or all of the following items:

Ia. Modify the far field boundary conditions for gust response prediction.

Ib. Exercise the multistage code for gust response prediction.

Ic. Assess the validity of the code by comparing with data of Ref. 6.

IIa. Exercise the viscous code for unsteady aerodynamic flow prediction with viscous effects.

IIb. Exercise the viscous code for the airfoils tested in Ref. 7.

IIc. Assess the validity of the code by comparing with experimental data.

REFERENCES

1. Reddy, T.S.R., et al, A Review of Recent Aeroelastic Analysis Methods for Propulsion at NASA Lewis Research Center, NASA TP-3406, 1993.

2. Reddy, T.S.R. and Srivastava, R., User's Guide for MSAP2D: A Program for Unsteady Aerodynamic and Aeroelastic (Flutter and Forced Response) Analysis of Multistage Compressors and Turbines, Version 1.0, in print.

3. Morel, M.R. and Murthy, D.V., Turbomachinery Forced Response Prediction System (FREPS) User's Manual, NASA CR-194465, 1994

4. Swafford, T.W., Loe, D.H., Huff, D.L., Huddleston, and Reddy, T.S.R., The Evolution of NPHASE Euler/Navier-Stokes Computations of Unsteady Two-Dimensional Cascade Flow Fields, AIAA-94-1834, 12th Applied Aerodynamics Conference, June 20-22, 1994, Colorado Springs, CO.

5. Verdon, J.M., Montgomery, M.D., and Kousen, K.A., Development of a Linearized Unsteady Euler Analysis for Turbomachinery Blade Rows, NASA CR 4677, 1995.

6. Kurkov, A.P. and Lucci, B.L., Measurement of Gust Response on a Turbine Cascade, ASME-95-GT-96, International Gas Turbine and Aeroengine Congress and Exposition, Houston, Texas, June 5-8, 1995.

7. Buffum, D.H., et al, An Experiment Investigation of Unsteady Flows at Large Incidence Angles in a Linear Oscillating Cascade, AIAA-96-2823, 32nd Joint Propulsion Conference and Exhibit, July 1-3, 1996.

8. Reddy, T.S.R., Gust and Structural Response Analysis of a 2D Cascade Using an Euler Aeroelastic Solver, AIAA-96-1492, 37th AIAA/ASME/ASCE/ASC Structures, Structural Dynamics, and Materials Conference and Exhibit, April 15-17, 1996, Salt Lake City, UT.

Budget Summary

From February 1, 1996 to October 31, 1997

			NASA USE ONLY	
		A	B	C
1.	Direct Labor (salaries, wages, and fringe benefits)	$59,255		
2.	Other Direct Costs			
	a. Subcontracts			
	b. Consultants			
	c. Equipment			
	d. Supplies			
	e. Travel	$ 1,200		
	f. Other			
3.	Indirect Costs	$9,545		
4.	Other Applicable Costs			
5.	Subtotal -- Estimated Costs	$70,000		
6.	Less Proposed Cost Sharing (if any)			
7.	Carryover Funds (if any)			
	a. Anticipated amount _____			
	b. Amount used to reduce budget			
8.	Total Estimated Costs	$70,000		XXXXXXX
APPROVED BUDGET		XXXXXXXX	XXXXXXXX	

Instructions

1. Provide a separate budget summary sheet for each year of the proposed research.

2. Grantee estimated costs should be entered in Column A. Columns B and C are for NASA use only. Column C represents the approved grant budget.

3. Provide in attachments to the budget summary the detailed computations of estimates in each cost category, along with any narrative explanation required to fully explain proposed costs.

NASA
Washington D.C

OMB Control No
1910-0400

National Aeronautics Space Administration

ASSURANCE OF COMPLIANCE

Nondiscrimination of Federally Assisted Programs

The University of Toledo (Hereinafter called the "Applicant")

HEREBY AGREES to comply with Title VI of the Civil Rights Act of 1964 (Pub. L.88-352), Section 16 of the Federal Energy Administration Act of 1974 (Pub.L.93-275), Section 401 of the Energy Reorganization Act of 1974 (Pub.L.93-438), Title IX of the Education Amendments of 1972, as amended (Pub.L.92-318, Pub.L.93-568, and Pub.L.94-482), Section 504 of the Rehabilitation Act of 1973 (Pub.L.93-112), the Age Discrimination Act of 1975 (Pub.L.94-135), Title VIII of the Civil Rights Act of 1968 (Pub.L.90-284), the Department of Energy Organization Act of 1977 (Pub.L.95-91), and the Energy Conservation and Production Act of 1976, as amended (Pub.L.94-385). In accordance with the above laws and regulations issued pursuant thereto, the Applicant agrees to assure that no person in the United States shall, on the ground of race, color, national origin, sex, age, or handicap, be excluded from participation in, be denied the benefits of, or be otherwise subjected to discrimination under any program or activity in which the Applicant receives Federal assistance from the Department of Energy.

Applicability and Period of Obligation

In the case of any service, financial aid, covered employment, equipment, property, or structure provided, leased, or improved with Federal assistance extended to the Applicant by the Department of Energy, this assurance obligates the Applicant for the period during which Federal assistance is extended. In the case of any transfer of such service, financial aid, equipment, property, or structure, this assurance obligates the transferee for the period during which Federal assistance is extended. If any personal property is so provided, this assurance obligates the Applicant for the period during which it retains ownership or possession of the property. In all other cases, this assurance obligates the Applicant for the period during which the Federal assistance is extended to the Applicant by the Department of Energy.

Employment Practices

Where a primary objective of the Federal assistance is to provide employment or where the Applicant's employment practices affect the delivery of services in programs or activities resulting from Federal assistance extended by the Department, the Applicant agrees not to discriminate on the ground of race, color, national origin, sex, age, or handicap, in its employment practices. Such employment practices may include, but are not limited to, recruitment, recruitment advertising, hiring, layoff or termination, promotion, demotion, transfer, rates of pay, training and participation in upward mobility programs; or other forms of compensation and use of facilities.

Subrecipient Assurance

The Applicant shall require any individual, organization, or other entity with whom it subcontracts, subgrants, or subleases for the purpose of providing any service, financial aid, equipment, property, or structure to comply with laws cited above. To this end, the subrecipient shall be required to sign a written assurance form, however, the obligation or both recipient and subrecipient to ensure compliance is not relieved by the collection or submission of written assurance forms.

Data Collection and Access to Records

The Applicant agrees to compile and maintain information pertaining to programs or activities developed as a result of the Applicant's receipt of Federal assistance from the Department of Energy. Such information shall include, but is not limited to, the following: (1) the manner in which services are or will be provided and related data necessary for determining whether any persons are or will be denied such services on the basis of prohibited discrimination; (2) the population eligible to be served by race, color, national origin, sex, age, and handicap; (3) data regarding covered employment including use or planned use of bilingual public contact employees serving beneficiaries of the program where necessary to permit effective participation by beneficiaries unable to speak or understand English; (4) the location of existing or proposed facilities connected with the program and related information adequate for determining whether the location has or will have the effect of unnecessarily denying access to any person on the basis of prohibited discrimination; (5) the present or proposed membership by race, color,national origin, sex, age, and handicap, in any planning or advisory body which is an integral part of the program; and (6) any additional written data determined by the Department of Energy to be relevant to its obligation to assure compliance by recipients with laws cited in the first paragraph of this assurance.

The Applicant agrees to submit requested data to the Department of Energy regarding programs and activities developed by the Applicant from the use of Federal assistance funds extended by the Department of Energy, Facilities of the Applicant (including physical plants, building, or other structures) and all records, books, accounts, and other sources of information pertinent to the Applicant's compliance with the civil rights laws shall be made available for inspection during normal business hours on request of an officer or employee of the Department of Energy specifically authorized to make such inspections. Instructions in this regard will be provided by the Director, Office of Equal Opportunity, U.S. Department of Energy.

This assurance is given in consideration of and of the purpose of obtaining any and all Federal grants, loans, contracts (excluding procurement contracts), property, discounts, or other Federal assistance extended after the date hereto, to the Applicants by the Department of Energy, including installment payments on account after such data of application for Federal assistance which are approved before such date. The Applicant recognizes and agrees that such Federal assistance will be extended in reliance upon the representation and agreements made in this assurance and the United States shall have the right to seek judicial enforcement of this assurance. This assurance in binding on the Applicant, its successors, transferees, and assignees, as well as the person whose signature appears below and who is authorized to sign this assurance on behalf of the Applicant.

(Date)

The University of Toledo
(Name of Applicant)

2801 West Bancroft St.

Toledo, OH 43606
(Address)

James L. Fry, Vice President for Research
(Authorized Official)

(419) 530-2844
(Applicant's Telephone Number)

(Enclosure 1)

Certification Regarding Drug-Free Requirements

A. The grantee certifies that it will provide a drug-free workplace by:

(a) Publishing a statement notifying employees that the unlawful manufacture, distribution, dispensing, possession or use of a controlled substance is prohibited in the grantee's workplace and specifying the actions that will be taken against employees for violation of such prohibition;

(b) Establishing a drug-free awareness program to inform employees about --

(1) The dangers of drug abuse in the work place;

(2) The grantee's policy of maintaining a drug-free workplace

(3) Any available drug counseling, rehabilitation, and employee assistance programs; and

(4) The penalties that may be imposed upon employees for drug abuse violations occurring in the workplace;

(c) Making it a requirement that each employee to be engaged in the performance of the grant be given a copy of the statement required by paragraph (a);

(d) Notifying the employee in the statement required by paragraph (a) that, as a condition of employment under the grant, the employee will --

(1) Abide by the terms of the statement and

(2) Notify the employer of any criminal drug statute conviction for a violation occurring in the workplace no later than five days after such conviction.

(e) Notifying the agency within ten days after receiving notice under subparagraph (d)(2) from an employee or otherwise receiving actual notice under subparagraph (d)(2), with respect to any employee who is so convicted--

(f) Taking one of the following actions within 30 days of receiving notice under subparagraph (d)(2), with respect to any employee who is so convicted--

(1) Taking appropriate personnel action against such an employee, up to and including termination; or

(2) Requiring such employee to participate satisfactorily in a drug abuse assistance or rehabilitation program approved for such purposes by a Federal, State, or local health, law enforcement, or other appropriate agency;

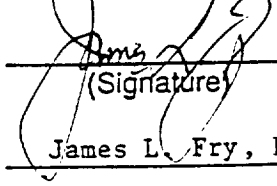
(g) Making a good faith effort to continue to maintain a drug-free workplace through implementation of paragraphs (a), (b), (c), (d), (e) and (f).

B. The grantee shall insert in the space provided below the site(s) for the performance of work done in connection with the specific grant:

Place of Performance (Street address, city, county, state, zip code)

NASA Lewis and The University of Toledo

Certified By:



10/2/96

(Signature) (Date)

James L. Fry, Ph.D.

(Typed Name)

Vice President for Research

(Title)

The University of Toledo

(Institution)

(Enclosure 1)

Proposal No.:_____

Principal Investigator: Dr. Theo Keith

Title: Aeroelastic Stability and Response of Rotating Structures

Certification Regarding Debarment, Suspension, and Other Responsibility Matters--Primary Covered Transactions

(1) The prospective primary participant certifies to the best of its knowledge and belief, that it and its principals:

(a) Are not presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department of agency;

(b) Have not within a three-year period preceding this proposal been convicted of or had a civil judgment rendered against them for commission of fraud or a criminal offense in connection with obtaining, attempting to obtain, or performing a public (Federal, State or local) transaction or contract under a public transaction; violation of Federal or State antitrust statutes or commission of embezzlement, theft, forgery, bribery, falsification or destruction of records, making false statements, or receiving stolen property;

(c) Are not presently indicted for or otherwise criminally or civilly charged by a governmental entity (Federal, State or local) with commission of any of the offenses enumerated in paragraph (1)(b) of this certification; and

(d) Have not within a three-year period preceding this application/proposal had one or more public transactions (Federal, State or local) terminated for cause or default.

(2) Where the prospective primary participant is unable to certify to any of the statements in this certification, such prospective participant shall attach an explanation to this proposal.

Certified By:

_____ 10/2/96
(Signature) (Date)

James L. Fry, Ph.D.
(Typed Name)

Vice President for Research
(Title)

The University of Toledo
(Institution)

(Enclosure 1)

CERTIFICATION REGARDING LOBBYING

Certification for Contracts, Grants, Loans, and Cooperative Agreements.

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No Federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned. to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooeprative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, "Disclosure Form to Report Lobbying," in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers (including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements) and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000, and not more than $100,000 for each such failure.

Certified by:

James L. Fry

Authorized Official (Signature)

10/2/96

Date

James L. Fry, Ph.D.

Typed Name

Vice President for Research

Title

The University of Toledo

Institution

Biographical Sketch for Theo Gordon Keith, Jr.

- **Vitae, listing only academic essentials**

CURRENT POSITION:

Distinguished University Professor,
Department of Mechanical Engineering,
The University of Toledo, Toledo, Ohio.

DEGREES RECEIVED:

BME, Fenn College, June 1964
MSME, University of Maryland, June 1968
PhD, University of Maryland, August 1971

EXPERIENCE:

September 1991 - Present	Distinguished University Professor Department of Mechanical Engineering The University of Toledo, Toledo, Ohio
June 1995-Present	Vice President Ohio Aerospace Institute Cleveland, Ohio
June 1990-June 1995	Director Ohio Aerospace Institute Cleveland, Ohio
January 1990 - Present	Professor in Residence Ohio Aerospace Institute Cleveland, Ohio
September 1981 - Present	Professor Department of Mechanical Engineering The University of Toledo, Toledo, Ohio
September 1977 - February 1986	Chairman Department of Mechanical Engineering The University of Toledo, Toledo, Ohio
September 1976 - September 1981	Associate Professor Department of Mechanical Engineering The University of Toledo, Toledo, Ohio
September 1971 -	Assistant Professor

September 1976	Department of Mechanical Engineering The University of Toledo, Toledo, Ohio
Summers of 1973, 1974, and 1976	Aerospace Engineer NASA Lewis Research Center Cleveland, Ohio
June 1964 - September 1971	Mechanical Engineer NSRDC Annapolis, Maryland

PUBLICATIONS:

over 150 journal articles, conference papers and reports

FUNDED RESEARCH:

over 100 awards totalling more than $10,000,000

COURSES TAUGHT:

over 40 at undergraduate and graduate levels

THESES DIRECTED:

40 MS and 21 PhD

PROFESSIONAL SOCIETIES:

ASME	- Fellow
AIAA	- Associate Fellow
ASEE	- member
Sigma Xi	- member, chapter secretary (1979), president elect (1980), president (1981-82).
Pi Tau Sigma	- member and faculty advisor (1976-1979)
SAE	- member and faculty advisor (1979-1984)
STLE	- member

HONORS AND AWARDS:

ASTM Student Award, 1963-1964
Pi Mu Epsilon
Phi Kappa Phi
Pi Tau Sigma
Sigma Xi
ASEE Summer Fellow, NASA, Cleveland, Ohio (1973-1974)
1977 University of Toledo Outstanding Teacher Award (cash award)

1978 Ralph R. Teetor SAE Award
1987 AIAA Associate Fellow
1988 University of Toledo Outstanding Research Award (cash award)
1988 ASME Fellow
1989 D. Raftopoulos Sigma Xi Award for Research (cash award)

Also, listed in:
International Who's Who in Engineering
Men of Achievement
American Men and Women of Science
Who's Who in Frontiers of Science & Technology
Who's Who in American Education
Who's Who in the Midwest
Who's Who in Technology Today
Who's Who in Science and Engineering
Who's Who in the World

***OTHER*:**

Initiated the SAE Student Chapter at the University of Toledo.
Journal reviewer for AIAA, STLE, ASME, Int'l. J. for Num. Methods in Fluids, Int'l. J. for Num. Methods in Engineering and Int'l. J. for Num. Methods in Heat and Fluid Flow
Book reviewer for Prentice-Hall, Allyn and Bacon, Harper Row and Hemisphere
Research Proposal reviewer for US Navy, NASA, NSF, Ohio Aerospace Institute and University of Toledo
Expert Witness for UT Legal Aid Society
Consultant for General Electric, Teledyne, B.F. Goodrich and the Ohio Aerospace Institute
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Experience:

Sept. 84 - present: Senior Research Associate, The University of Toledo, and Resident Research Associate, NASA Lewis Research Center, Cleveland, Ohio.

Developed computational aeroelastic analysis methods for propfans, and ducted fans. Developed both single blade row and multistage aeroelastic analysis codes. Worked on response and stability analysis of propfans with empirical stall models. Assisted in validating actual designs for engine companies. Worked in propfan, supersonic through flow fan, high bypass ducted fan projects for aeroelastic analysis. Conversant with **all** the aeroelastic methods / codes developed for turbomachinery at NASA Lewis Research Center. Proposed APPLE, a distributed network of workstations for aeroelastic analysis using all the methods developed at NASA Lewis Research Center

May 82- August 84: National Research Council(USA) Research Associate, NASA Ames Research Center, CA 94036. Worked on the Aeroelastic Stability of Elastic Helicopter Rotors with dynamic inflow.

Sept'79- April 82: Project Assistant, Research Associate, Hindustan Aeronautics Limited - Indian Institute of Science Helicopter Program. Worked on coupled rotor body stability and symbolic manipulation in Helicopter aeroelasticity.

Educational Qualifications:

1980: Ph.D. in Engineering, Dept. of Aeronautics, Indian Institute of Science, Bangalore, India. Worked on developing a higher order shell theory to analyze static response and vibration analysis of isotropic and composite cylindrical shells.
Thesis Title: A HIGHER ORDER SHELL THEORY.

1974: M.E. in Civil Engineering, Indian Institute of Science, Bangalore, India. Course work included structural dynamics, Matrix analysis of structures, Analysis of Plates and Shells. passed in Distinction.

1972: B.E. in Civil Engineering, Andhra University, Kakinada, Andhra Pradesh, India. FIRST RANK, passed in Distinction.

Areas of Interest:

Finite Element Methods, Vibrations, Aeroelasticity, Computational Aeroelasticity, Turbomachinery Blade Dynamics, Composites, Symbolic Manipulation with FORTRAN, Analysis of Beams, Plates, and Shells, Multidisciplinary design and optimization.

Honors:

1) National Research Council Post-Doctoral Fellowship; 2) Indian Institute of Science Research Associateship; 3) The following prizes for securing First Rank in B.E. a) S. Nanjundayya Medal, b) Bhagavatula Venkata Subbaiah Prize,c) A.S. Lakshmanaswamy Naidu Memorial Prize, 4) State Government Merit Scholarship throughout B.E.

Awards:

Two NASA Technical Brief Awards; Two Structural Dynamics Branch, NASA Lewis Research Center, Best Paper Awards.

Membership and Professional Activities:

Senior Member AIAA, Reviewer for AIAA Journals, NASA technical reports, and AIAA conference papers.

Publications (coauthors in brackets):

User's Guide for MSAP2D: A Program for Unsteady Aerodynamic and Aeroelastic (Flutter and Forced Response) Analysis of Multistage Compressors and Turbines, NASA CR, in print, August 1996.

A Numerical Aeroelastic Stability Analysis of a Ducted-Fan Configuration, AIAA 96-2671, 32nd Joint Propulsion Conference, July 1-3, 1996, Lake Buena Vista, FL (R. Srivastava and G.L. Stefko).

Gust and Structural Response Analysis of a 2D Cascade Using an Euler Aeroelastic Solver, AIAA-96-1492,1996, 37th SDM, April 15-17, Salt Lake City, UT (R. Srivastava).

PROP3D: A Program for 3D Euler Unsteady Aerodynamic and Aeroelastic (Flutter and Forced Response) Analysis of Propellers, Version 1.0, NASA CR 198471, April 1996 (R. Srivastava).

ASTROP2 Users Manual: A Program for Aeroelastic Stability Analysis of Propfans, Version 2.0, NASA TM 107195, March 1996 (J.M. Lucero).

Aeroelastic Analysis of Ducted Rotors, presented at the International Symposium on Computational Fluid Dynamics in Aeropropulsion, 12-17, November 1995, San Francisco, CA (R. Srivastava)

User's Guide for ECAP2D: An Euler Unsteady Aerodynamic and Aeroelastic Analysis Program for Two Dimensional Oscillating Cascades, Version 1.0, NASA CR 189146, April 1995.

The Evolution of NPHASE: Euler/Navier-Stokes Computations of Unsteady Two-Dimensional Cascade Flow Fields, AIAA-94-1834,12th Applied Aerodynamics Conference, June 20-22, 1994, Colorado Springs, CO(Swafford, T.W., Loe, D.H., Huff, D.L., Huddleston, D.H.)

Flutter Analysis of Propfans Using a Three Dimensional Euler Solver, AIAA 94-1549,1994, 35th SDM, April 18-20, Hilton Head, SC (R. Srivastava)

Analysis of a Rotor-Stator stage using a two-dimensional Euler aeroelastic solver, AIAA 94-1638, 1994, 35th SDM, April 18-20, Hilton Head, SC (R. Srivastava)

Forced Response Analysis Using a Multistage Euler Aeroelastic Solver, AIAA-94-0739, 32nd Aerospace Sciences Meeting & Exhibit, January 10-13, 1994, Reno, NV (R. Srivastava).

Subsonic/Transonic Cascade Flutter Using a Full-Potential Solver, AIAA Journal, vol. 31, no. 7, pp. 1347-1349, 1993 (M.A. Bakhle, T.G. Keith, Jr.)

Unsteady Rotor-Stator interaction Including Aeroelastic Effects, AIAA-93-2237, 29th Joint Propulsion Conf., June 28-30, 1993, Monterey, CA (R. Srivastava)

Unsteady Aerodynamics and Flutter of Propfans using a 3D full potential solver, AIAA Paper 93-1633, 34th SDM, April 19-22, La Jolla, CA (M.A. Bakhle)

Aeroelastic Analysis Methods for Turbomachines and Propfans, Proc. Int. Symposium on Aerospace and Engineering, vol. 1, Ed. H.S. Mukunda and A.V.K. Murty, Dec. 12-15, 1992, Indian Institute of Science, Bangalore, India.

A Review of Recent Aeroelastic Analysis Methods for Propulsion at NASA Lewis Research Center, NASA TP 3406, 1993(M.A. Bakhle, R. Srivastava, O. Mehmed, G.L. Stefko)

APPLE: An Aeroelastic Analysis System for Turbomachines and Propellers, AIAA-92-2119, 4th AIAA/USAF/OAI Sept. , Cleveland, OH, 1992(M.A. Bakhle, R. Srivastava, O. Mehmed).

Flutter Analysis of Supersonic Axial Flow Cascades Using a High Resolution Euler Solver, Part 1: formulation and validation, NASA TM 105798, 1992 (M.A.Bakhle, D.H. Huff, T.W. Swafford)

An Investigation of Cascade Flutter using a 2D full potential Solver, AIAA Paper 92-2119, AIAA Dynamics Specialists Conference, Dallas, Texas, April 16-17, 1992. (M.A. Bakhle, T.G. Keith, Jr.)

Analysis of Cascades Using a Two-Dimensional Euler Aeroelastic Solver, AIAA Paper 92-2370, 33rd SDM meeting, April 15-18, 1992, Dallas. (M .A. Bakhle, D.L. Huff, T.W. Swafford)

A Numerical Classical Flutter Analysis of Advanced Propellers AIAA Paper 92-2119, AIAA Dynamics Specialists Conference, Dallas,Texas, April 16-17, 1992. (R. Srivastava, O. Mehmed)

Aeroelastic Analysis of Advanced Propellers Using an Efficient Euler Solver, AIAA-92-0488, 30th Aerospace Sciences Meeting, Reno, Jan. 6-9, 1992. (R. Srivastava, O. Mehmed)

Flutter Analysis of Cascades Using a Two-Dimensional Euler Solver, AIAA-91-1681, 22nd Fluid Dynamics, Plasmadynamics & Lasers Conference, Honolulu, Hawaii, June 24-27, 1991 (M .A. Bakhle, D.L. Huff, T.W. Swafford)

Euler Flow Predictions for an Oscillating Cascade Using a High Resolution Wave-Split Scheme, ASME paper 91-GT-198, 1991, 36th ASME International Gas Turbine and Aeroengine Congress and Exposition, June 3-6, 1991, Orlando, Florida (D.L. Huff, T.W. Swafford).

Time Domain Flutter Analysis of Cascades Using a Full-Potential Solver, AIAA J., vol. 30, no.1, Jan. 1992, pp. 163-170, AIAA Paper 90-0984, 1990 (M.A. Bakhle. T.G. Keith, Jr.)

Application of an Efficient Hybrid Scheme for Aeroelastic Analysis of Advanced Propellers, J. Propulsion and Power, vol. 7, no.3, Sept-Oct. 1991, pp. 767-775, AIAA Paper 90-0028, 1990.(R. Srivastava, N.L. Sankar, and D.L. Huff)

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The Effects of Rotational flow, Viscosity, Thickness and Shape on Transonic Flutter Dip Phenomena, NASA TM 100811, presented at 29th AIAA Structures, Structural Dynamics and Materials Conference, Williamsburgh, April 18-20, 1988(R. Srivastava, K.R.V. Kaza).

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